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3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	BRITISH TELECOMMUNICATIONS public limited company 81 NEWGATE STREET LONDON, EC1A 7AJ, England Registered in England: 1800000
	Patents ADP number *(if you know it)*	1867002
	If the applicant is a corporate body, give the country/state of its incorporation	UNITED KINGDOM
4.	Title of the invention	COMMUNICATIONS NETWORK
5.	Name of your agent *(if you have one)*	ROBERTS, Simon Christopher
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COMMUNICATIONS NETWORK

Field of the invention

The present invention relates to a communications network and to a device for retiming a data pulse carried on such a network.

Background

It is well known that optical fibre has a huge potential information-carrying capacity. For example, by utilising the entire gain bandwidth of erbium-doped optical amplifiers, a single fibre could carry more than 2 Tbit/s. However in the majority of telecommunications systems in commercial use currently, the information is carried over fibre in the form of an optical signal at a single wavelength. The data transmission bandwidth of the fibre is therefore limited by the electrical bandwidth of the transmitter and receiver, and this means that only a tiny fraction (a maximum of about 1%) of the potential bandwidth-carrying capacity of the fibre is being usefully exploited. There is therefore much interest currently in developing methods for increasing the transmission rate for point-to-point fibre links. One method is wavelength-division multiplexing (WDM), in which several data channels, at different wavelengths, are carried simultaneously on the same fibre. An alternative method for increasing the rate of information that can be carried on fibre is to use optical time-division multiplexing (OTDM) in which several data channels are multiplexed in the form of bit-interleaved return-to-zero (RZ) optical pulse trains.

The WDM approach to photonic networking has some very attractive advantages: in addition to the relative simplicity and commercial availability of the devices needed, WDM networks can be created in a wide variety of architectures with great flexibility (the main restriction being merely that any pair of photonic transmission paths cannot use the same wavelength on a shared fibre link). An advantage of WDM networks is that they can, in principle, support 'signal transparency', i.e. data signals can be carried using any modulation format. However, this implies that, in effect, WDM photonic networks are based on 'analogue' transmission. As a result it is not possible for digital signal regeneration techniques in the optical domain, to be used. The inability to perform signal regeneration in the optical domain leads to practical scaling limitations for WDM networks due to noise accumulation from optical amplifiers, crosstalk and nonlinearity. These factors restrict the number of network switching

nodes through which signals can pass without fatal degradation. Currently, in reported laboratory experiments the maximum number of WDM switching nodes through which a signal can pass without regeneration is limited to around 10, which is a significant restriction in architecture and scalability. A feasible, though costly, solution currently being advocated by some equipment vendors is to sacrifice transparency, standardise the transmission format, and regenerate each wavelength channel individually at the outputs of WDM cross-connects. In effect, this is a hybrid arrangement using analogue switching together with channel-by-channel digital regeneration.

In the OTDM approach to photonic networking, the signals are carried in 'digital' format in the form of RZ optical pulses, allowing the use of digital signal regeneration techniques in the optical domain such as 3R (Re-amplify, Re-time and Re-shape) regeneration [Lucek J K and Smith K,Optics Letters, 18, 1226-28 (1993)] or soliton-control techniques [Ellis A D, Widdowson T, Electronics Letters, 31, 1171-72 (1995)]. These techniques can maintain the integrity of the signals as they pass through a very large number of nodes. For example, Ellis and Widdowson [Ellis A D, Widdowson T, Electronics Letters, 31, 1171-72 (1995)] have made a laboratory demonstration of error-free transmission of signals through an OTDM network consisting of 690 nodes in concatenation. Despite this impressive potential for scalability, however, the OTDM approach to photonic networking suffers from severe restrictions in the network architecture that can be used. This results from the need to maintain proper bit-level synchronism between all the signal sources, demultiplexers and channel add/drop multiplexers throughout the network.

The problems with the conventional techniques discussed above, are that in complex architectures, timing fluctuations in the arrival time of pulses at nodes (due to environmental effects acting on the fibres such as temperature change and mechanical strain) cannot be adequately controlled or compensated in a continuous uninterrupted fashion. This results in data pulses being lost. There are many causes of timing fluctuations that may result in data being lost. The first cause is jitter in the arrival time of the incoming packet data pulses. It is well known that in high-speed optical transmission systems, jitter in the arrival time of pulses arises from effects such as amplified spontaneous emission noise, the soliton self-frequency shift arising

from the Raman effect, soliton short-range interactions, and the complex interplay of these various processes. Other timing fluctuations include temperature dependent length changes in the fibre that cause the absolute arrival time of the optical pulses at a node to wander. This creates timing problems for demultiplexing the data at the node and for adding new local data to the optical stream.

Conventional techniques to compensate for timing fluctuations, such as jitter, rely upon a gate window being opened by the data pulse when it reaches the node. The problem with this technique is that the gate window only has a finite duration, and if a data pulse is so badly affected by jitter that it does not arrive within the gate window, it will be lost. Further, if two data pulses were to suffer jitter or other time fluctuations to the extent that they were both to fall within the same sampling window, only one retimed pulse would be generated. The second pulse that fell within the sampling window would be lost.

Summary of the invention

The present invention provides a device for retiming a data pulse which is capable of retiming the data pulse irrespective of the degree of timing fluctuation the data pulse has suffered within the period of the data pulse, and overcomes some of the disadvantages of the prior art retiming techniques discussed above.

In accordance with a first aspect of the present invention, there is provided according to a first embodiment a device for retiming an optical data pulse, whereby a data pulse, whose arrival time at a node may be temporally offset from its predicted arrival time, is retimed so that it is received at a detector disposed downstream of said node at a predetermined time, said device comprising a node disposed to receive said data pulse and an optical chirped pulse comprising a plurality of continuous segments, wherein each segment has a predetermined wavelength, whereby at said node, said data pulse operates on said chirped pulse to generate a pulse, which is output from said node, and whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse said data pulse operates on, said device further comprising dispersion means for dispersing said generated pulse in accordance with its wavelength, so that said generated pulse arrives at a detector disposed.

Thus, in accordance with the invention, regardless of the arrival time of the data pulse at the node, a pulse will be generated and subsequently dispersed, so as to arrive at a detector at a predetermined time.

According to a second aspect, there is provided a device for retiming a plurality of optical data pulses, whereby a plurality of optical data pulses, whose arrival time at a node may be temporally offset from their predicted arrival time, are retimed so that they is received at a detector disposed downstream of said node equally spaced in time, said device comprising a node disposed to receive said data pulses and a stream of optical chirped pulses, each comprising a plurality of continuous segments, wherein each segment has a predetermined wavelength, whereby at said node, said data pulses operate on said chirped pulses to generate pulses, which are output from said node, and whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse each of said data pulses operates on, said device further comprising dispersion means for dispersing said generated pulses in accordance with their wavelength, so that said generated pulses arrive at a detector disposed downstream of said node equally spaced in time.

Thus, a further advantage of this embodiment of the invention is that two consecutive data pulses whose arrival time at the node is temporally offset, will arrive at the detector equally spaced in time. In a conventional retiming device, if pulse do not fall within the sampling window of the regenerator, they will be lost. According to the present invention, because the chirped pulse comprises a plurality of continuous segments, its sampling window is effectively extended. Thus, a second data pulse which falls outside the sampling window of a conventional regenerator does not fall outside the sampling window of the chirped pulse of the present invention.

According to a third aspect, there is provided a method for retiming a data pulse, whereby a data pulse, whose arrival time at a node may be temporally offset from its predicted arrival time, is retimed so that it is received at a detector disposed downstream of said node at a predetermined time, said method comprising the steps of:

receiving at a node said data pulse and an optical chirped pulse comprising a plurality of continuous segments, wherein each segment comprises a predetermined wavelength,

operating said data pulse on said chirped pulse to generate a pulse, whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse said data pulse operates on,

outputting said generated pulse from said node,

dispersing said generated pulse in accordance with its wavelength, so that said generated pulse arrives at a detector disposed downstream of said node at a predetermined time.

According to a fourth aspect, there is provided a method for retiming a plurality of data pulses, whereby a plurality of data pulses, whose arrival time at a node may be temporally offset from their predicted arrival time, are retimed so that they are received at a detector disposed downstream of said node equally spaced in time, said method comprising the steps of:

receiving at a node said plurality of data pulses and a stream of optical chirped pulses, each comprising a plurality of continuous segments, wherein each segment comprises a predetermined wavelength,

operating said data pulses on said chirped pulses to generate pulses, each of whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulses said data pulses operate on,

outputting said generated pulses from said node,

dispersing said generated pulses in accordance with the wavelength of each pulse, so that said generated pulses arrive at a detector disposed downstream of said node equally spaced in time.

According to a fifth aspect, there is provided a regenerator comprising a device according to claim 1, wherein said regenerator comprises: a second node disposed to receive said generated pulse and a local clock pulse, wherein said node is arranged so that said generated pulse operates on said local clock pulse to produce a regenerated pulse having a wavelength determined by said local clock pulse and independent of the wavelength of the pulse received at said second node.

The retimer of the present invention is compatible with other optical devices such as regenerators and bit-serial optical processing devices.

Brief description of the drawings

In order that the invention may be more fully understood embodiments thereof will now be described by way of example, and by way of contrast with a prior art device as previously described, reference being made to the accompanying drawings in which:

Figure 1: shows a device for retiming a data pulse according to a first embodiment of the present invention;

Figure 2: shows a depiction of a prior art retiming technique;

Figure 3: shows a device for retiming data pulses according to a second embodiment of the present invention;

Figure 4: shows a plurality of chirped pulses

Figure 5: shows a representation of how the chirped pulses are generated;

Figure 6: shows a regenerator including a device according to the first embodiment of the present invention.

Detailed description

Figure 2 shows a prior art approach to retiming timing fluctuations of a digital data stream consisting of a RZ pulse train encoded by on-off modulation ("mark" represents a bit value 1, "space" represents 0). The incoming data bits from a distant source 20 are used to modulate using a gate 24, a continuous train of RZ pulses produced by a local source 22, thus regenerating the original data to be detected at remote detector 26. The presence of a "mark" in the incoming data stream causes the gate to open for a time of the order of the bit period, allowing a single pulse from the local source 14 to pass through. In this way the regenerated bits are provided by the local source and hence their pulse shape, spectral quality, amplitude and timing stability are determined by the properties of the local source 22. The pulse repetition rate of this local source 22 is the same as the bit rate of the incoming data. The key problem is designing such a regenerator is to ensure that the incoming data stream and the locally-generated pulses are maintained in synchronism. As soon as the two

become out of synchronism, pulses that have suffered timing fluctuations such as jitter, may not arrive at the node within the time period the gate is open and will thus fail to be regenerated.

Figure 1 is a simplified outline diagram showing a device for retiming a data pulse according to the first embodiment of the invention. An optical data source 30 could consist of a source of optical RZ pulses at a repetition frequency of, for example 10GHz, whose output is modulated and multiplexed in a fashion similar to that used for OTDM (i.e. the output from the pulse source is split into parallel paths which are individually encoded with data by on-off modulation at a particular rate and then recombined by bit-interleaving to form a packet of data bits with a composite rate). The source of pulses at the particular rate could consist of an electronic microwave oscillator oscillating at the same rate which drives an electrically-synchronised laser (such as a gain-switched laser or an actively mode locked laser). Alternatively, it could be a continuously free-running optical pulse source, such as a passively-mode locked laser or a mode locked ring laser, whose nominal repetition frequency is set (for example, by tuning the laser cavity length). A further chirped pulse source 32 produces a source of chirped pulses at a predetermined repetition rate. The source provides, in particular, a source of RZ chirped pulses which is continuously free-running and independent from the data pulse source. The chirped pulse source 32 can be either a local source, local to the node 10 or remote to the node 10.
Figure 4 shows the frequency characteristics of the chirped pulses and Figure 5 outlines the generation of the chirped pulses. These aspects are discussed below. The chirped pulses thus generated have a duration of approximately 100ps for a data rate of 10Gbit/s, and are passively multiplexed to form a continuous stream of pulses. Further, for example, where T is the nominal bit period in the optical packet, if $T=10ps$, $1/T= 100Gbit/s$. Although it is not essential that the bit rate of the data source and the chirped source are the same, it is preferable that they lie close to the same nominal value, $1/T$, where T is the nominal bit period.

The node comprises an optical gate 12, preferably an optical AND gate. The optical gates may be implemented in different ways. For ultrafast operation, the gate 12 could be a nonlinear optical device such as a fibre loop mirror (as described, for example, by Whitaker et al in Optics Letters, vol. 16, page 1840 (1991)), in which

case the gate width is defined by selecting suitable fibre lengths, dispersion and birefringence. Alternatively a suitable ultrafast gating device based on the nonlinearity in semiconductor optical amplifiers could be used (as described, for example, by Kang et al in the International Journal of High Speed Electronics and Systems, vol. 7, page 125 (1996)). In this case the gate width may be determined by the positioning of the amplifier in a Sagnac interferometer loop arrangement, or the relative offset of two amplifiers in a Mach-Zehnder interferometer device. Another suitable ultrafast semiconductor-based device is the ultrafast nonlinear interferometer switch described by Hall and Rauschenbach (paper PD5, Proceedings of Conference on Optical Fiber Communication OFC'98, published by the Optical Society of America, February 1998), which has been shown to operate at a speed of 100 Gbit/s. For operation at lower speeds an optoelectronic device such as an electroabsorption modulator could be used as the gate. In that case, the incoming packet data bits must first be received by a photodetector whose output is converted to a suitable short electrical pulse to drive the modulator, and the gate width is defined by the width and amplitude of this electrical pulse. In this case, for correct operation it is necessary that the photodetector and associated electronics can fully resolve the data bits, which limits the packet data rate. The AND gate function can also be achieved by four-wave mixing (FWM) in an optical fibre or semiconductor optical amplifier. Other techniques include optical cross-correlation in a nonlinear crystal or two-photon absorption in a semiconductor.

When the data pulse dp arrives at the node, it operates on the chirped pulse cp arriving at the gate 12 of the node 10. The operation of the data pulse dp on the chirped pulse cp through the optical AND gate 12, has the effect of selecting a segment from the chirped pulse. For example, in a NOLM this segment is selected because the nonlinearity is instantaneous and it is only the frequencies of the chirped pulse cp that travel at the same group velocity within the fibre that interact with the data pulse dp. This results in only a part of the chirped pulse being transmitted at the output of the interferometer.
Depending on the particular experimental arrangement, the selected segment can have the same pulse shape, spectral quality and amplitude as the data pulse. However, this is not necessary. The optical AND gate can be chosen to vary any of

these properties of the generated pulse. However, because the chirped pulse cp comprises a variable frequency range depending upon the temporal offset within the pulse, the wavelength of the selected segment is determined in accordance with where the data pulse falls within the duration of the chirped pulse.

Thus, the frequency of the pulse 16 outputted from the gate 12 is dependent upon its temporal offset with respect to the chirped pulse cp. This arrangement provides the advantage that regardless of the fluctuation of the arrival time of the data pulse, it will always operate on some portion of the chirped pulse to produce a pulse.

The pulse outputted by the gate 12 is then subject to dispersion means 14. The dispersion means 14 may comprise any dispersion compensation means such as a length of dispersion compensated optical fibre or a grating. The dispersion compensation means 14 can be selected, for example by varying the length of dispersion compensated fibre so that the arrival time of the pulse output can be set regardless of the wavelength of the pulse output by the gate. Thus, the advantage of this arrangement is that any pulse outputted by the gate will arrive after a predetermined time at the detector 18.

It is thus appreciated, that according to the present invention, the pulse arriving at the node 10 may suffer severe jitter, yet pulses arriving at the detector 18 arrive at a predetermined time. In this way the data pulses are retimed.

Figure 3 shows a device for retiming data pulses according to a second embodiment of the present invention. In particular, Figure 3 shows how a plurality of pulses are retimed so that they arrive at the detector 18 equally spaced in time. The device shown in Figure 3 works according to the same principle as described with respect to Figure 2. According to Figure 3 a plurality of optical data pulses dp1, dp2, dp3 produced by data source 30, reach a remote node 10 having suffered time fluctuations. For example dp1 and dp2 are temporally displaced by a time deltat12, and dp2 and dp3 are temporally displaced by a time delta23. Each data pulse dp1, dp2, dp3 in the node 10 operates on respective chirped pulses cp1, cp2, cp3. The output of the node comprises three pulses 160, 162, 164, lambda1, lambda2 and lambda3, whereby although the pulse shape of these pulses is the same as their corresponding data pulses, their wavelength, as discussed above is dependent upon the temporal offset of each pulse with respect to the chirped pulse.

After leaving the node 10 pulses 160, 162, 164: lambda1, 2 and 3, are nevertheless still subject to time fluctuations with respect to each other, delta12 and delta23. The delay means comprising dispersion compensation means 14 disperses pulses 160, 162, 164 in accordance with each of their wavelength's respectively, so that 180, 182, 184: lambda1,2 and 3 arrive equally spaced in time at the detector 18.

Figure 4 shows a plurality of chirped pulses. The frequency characteristic of the pulses is that of a saw tooth with respect to time. Figure 4 depicts chirped pulses that are linearly chirped. That is over the period of the pulse the wavelength, and hence, frequency of the pulse increases linearly. However, provided the dispersion means are compensated appropriately, there is no reason why non-linearly chirped pulses may not be used.

The dotted line on Figure 4 represents a schematic indication of the amplitude of the chirped pulses. The chirped pulses generated according to the method described below, are preferably square shaped, having a sharp rise time. It is however, envisaged that chirped pulses having other characteristics could also be used.

Chirped pulses as such are known. For example, Uchiyama K, Takara H, Morioka T, Kaweanishi S and Saruwatari M, Electronics Letters. Vol 32, No. 21, 10th October 1996, discloses the use of chirped pulses for the different application of converting TDM signals (time division multiplexing) to WDM signals (wavelength division multiplexing).

Figure 5 shows one example of how chirped pulses are generated. A mode locked laser is used to generate optical pulses at 10GHz at a predetermined wavelength. The laser output is fed into a length of non-linear optical fibre, such as Sumitomo fibre The pulses whilst propagating in the portion of non-linear optical fibre undergo self phase modulation which has the effect of broadening the frequency spectrum of the light within each pulse by an amount deltav. Having undergone spectrum broadening, the pulses are then fed into a portion of ordinary optical fibre. The pulses whilst propagating in the ordinary portion of fibre undergo group velocity dispersion. Thus, the duration of the pulses increases by an amount deltat. Thus, the output from the portions of fibre are chirped pulses. These chirped pulses are broadened both in terms of their frequency spectrum, deltav, and their duration, deltat.

Two subsequent modulation stages ensure that the chirped pulses are shaped. Electroabsorption modulation removes the edges to reduce the rise time of the pulses. A further modulation stage, for example using a lithium niobate modulator flattens the top of each chirped pulse by selectively attenuating the peaks of the chirped pulse. The pulses generated in this manner have a duration of 100ps. This period however, can be varied by selecting the portion of ordinary fibre used. Further the frequency spectrum of the chirped pulses can be varied by selecting the portion of the non-linear fibre used or by varying the input power to the fibre to change the non-linear broadening effect.
It can be understood, that by using the method described above, the characteristics of the chirped pulses can be varied.

Figure 6 shows a regenerator 40 including a device according to the first embodiment of the present invention. The device for retiming data pulses has application as a pre-stage for a regenerator 40, such as those regenerators disclosed in our pending unpublished application GBA 9808491. As can be seen from Figure 6, the output from the device for retiming having equally spaced pulses T but of differing wavelengths lambda1, lambda 2 and lambda 3 etc, is input to a further node 42 comprising a further AND-gate 42. A local clock pulse 44 is also input to the and-gate. The pulses lambda 1, 2 and 3, operate on the clock pulses to generate a regenerated optical pulse lambda0 having the same pulse shape, spectral quality, amplitude and timing stability as the local source 44. However, because the input pulses lambda1, lambda 2, lambda3 are equally spaced in time by period T, it is extremely unlikely that any data will be lost.

CLAIMS

1. A device for retiming an optical data pulse, whereby a data pulse, whose arrival time at a node may be temporally offset from its predicted arrival time, is retimed so that it is received at a detector disposed downstream of said node at a predetermined time, said device comprising a node disposed to receive said data pulse and an optical chirped pulse comprising a plurality of continuous segments, wherein each segment has a predetermined wavelength, whereby at said node, said data pulse operates on said chirped pulse to generate a pulse, which is output from said node, and whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse said data pulse operates on, said device further comprising dispersion means for dispersing said generated pulse in accordance with its wavelength, so that said generated pulse arrives at a detector disposed downstream of said node at a predetermined time.

2. A device for retiming a plurality of optical data pulses, whereby a plurality of optical data pulses, whose arrival time at a node may be temporally offset from their predicted arrival time, are retimed so that they is received at a detector disposed downstream of said node equally spaced in time, said device comprising a node disposed to receive said data pulses and a stream of optical chirped pulses, each comprising a plurality of continuous segments, wherein each segment has a predetermined wavelength, whereby at said node, said data pulses operate on said chirped pulses to generate pulses, which are output from said node, and whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse each of said data pulses operates on, said device further comprising dispersion means for dispersing said generated pulses in accordance with their wavelength, so that said generated pulses arrive at a detector disposed downstream of said node equally spaced in time.

3. A method for retiming a data pulse, whereby a data pulse, whose arrival time at a node may be temporally offset from its predicted arrival time, is retimed so that it is received at a detector disposed downstream of said node at a predetermined time, said method comprising the steps of:

receiving at a node said data pulse and an optical chirped pulse comprising a plurality of continuous segments, wherein each segment comprises a predetermined wavelength,

operating said data pulse on said chirped pulse to generate a pulse, whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse said data pulse operates on,

outputting said generated pulse from said node,

dispersing said generated pulse in accordance with its wavelength, so that said generated pulse arrives at a detector disposed downstream of said node at a predetermined time.

4. A method for retiming a plurality of data pulses, whereby a plurality of data pulses, whose arrival time at a node may be temporally offset from their predicted arrival time, are retimed so that they are received at a detector disposed downstream of said node equally spaced in time, said method comprising the steps of:

receiving at a node said plurality of data pulses and a stream of optical chirped pulses, each comprising a plurality of continuous segments, wherein each segment comprises a predetermined wavelength,

operating said data pulses on said chirped pulses to generate pulses, each of whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulses said data pulses operate on,

outputting said generated pulses from said node,

dispersing said generated pulses in accordance with the wavelength of each pulse, so that said generated pulses arrive at a detector disposed downstream of said node equally spaced in time.

5. A regenerator comprising a device according to claim 1, wherein said regenerator comprises:

a second node disposed to receive said generated pulse and a local clock pulse, wherein said node is arranged so that said generated pulse operates on said local clock pulse to produce a regenerated pulse having a wavelength determined by said local clock pulse and independent of the wavelength of the pulse received at the second node.

ABSTRACT

Communications Network

A device for retiming an optical data pulse, whereby a data pulse, whose arrival time at a node may be temporally offset from its predicted arrival time, is retimed so that it is received at a detector disposed downstream of said node at a predetermined time, said device comprising a node disposed to receive said data pulse and an optical chirped pulse comprising a plurality of continuous segments, wherein each segment has a predetermined wavelength, whereby at said node, said data pulse operates on said chirped pulse to generate a pulse, which is output from said node, and whose wavelength is determined in accordance with which of said plurality of segments of said chirped pulse said data pulse operates on, said device further comprising dispersion means for dispersing said generated pulse in accordance with its wavelength, so that said generated pulse arrives at a detector disposed downstream of said node at a predetermined time.

Figure 1

Figure 1

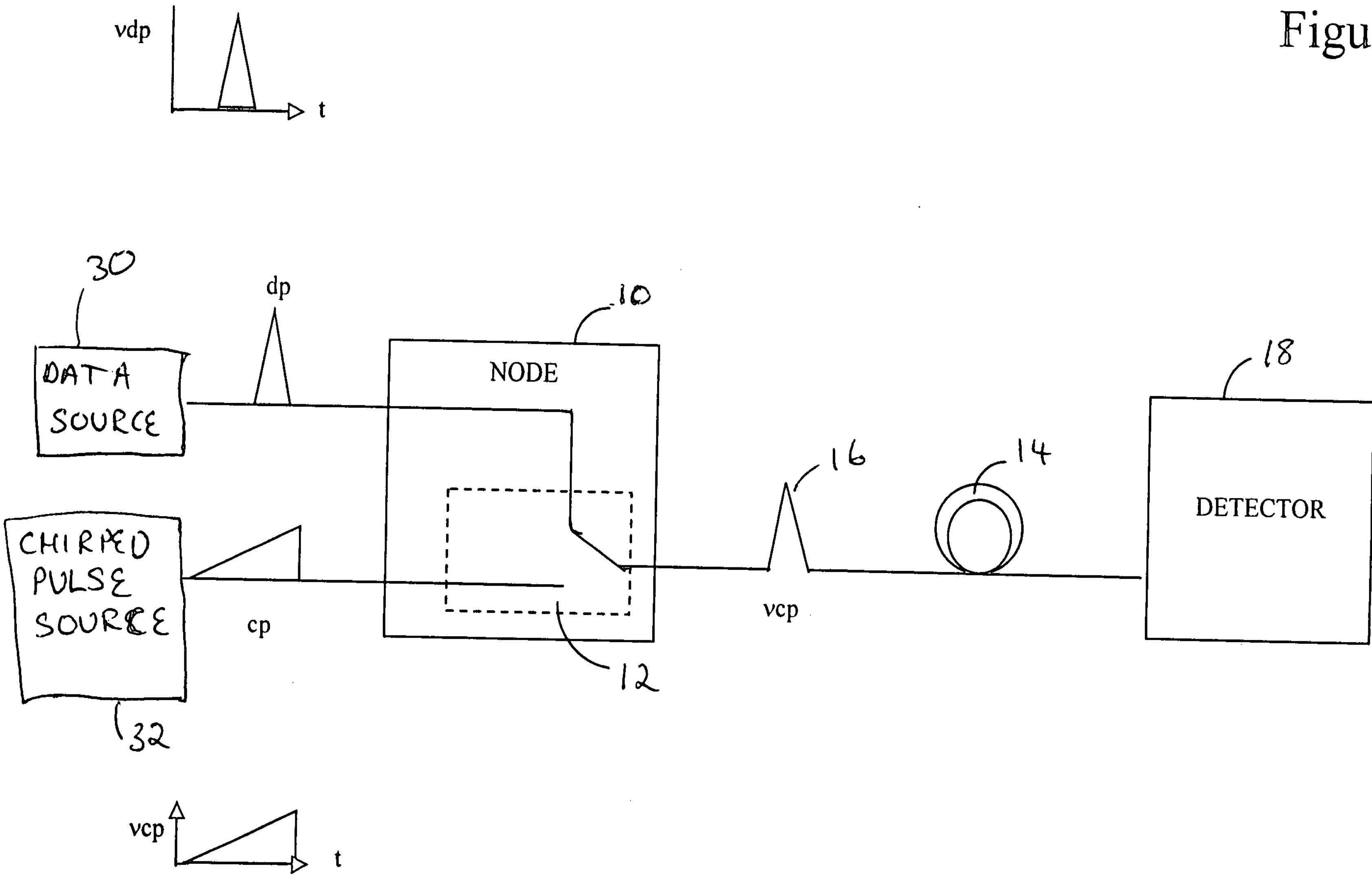
vdp
t
30
DATA SOURCE
dp
10
NODE
18
DETECTOR
16
14
CHIRPED PULSE SOURCE
cp
vcp
12
32
vcp
t

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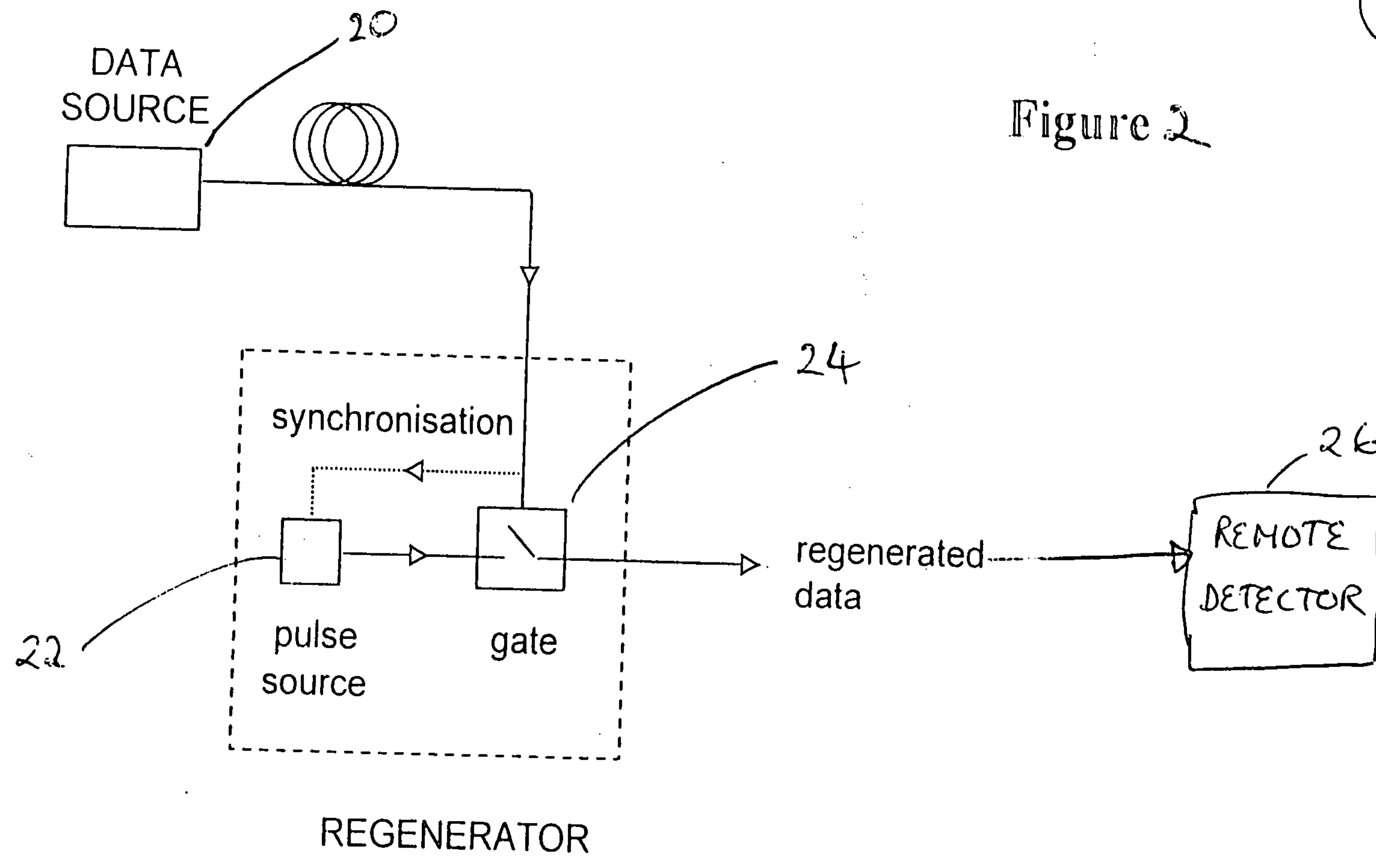
Figure 2



20
DATA
SOURCE
24
synchronisation
26
REMOTE
DETECTOR
regenerated
data
22
pulse
source
gate
REGENERATOR

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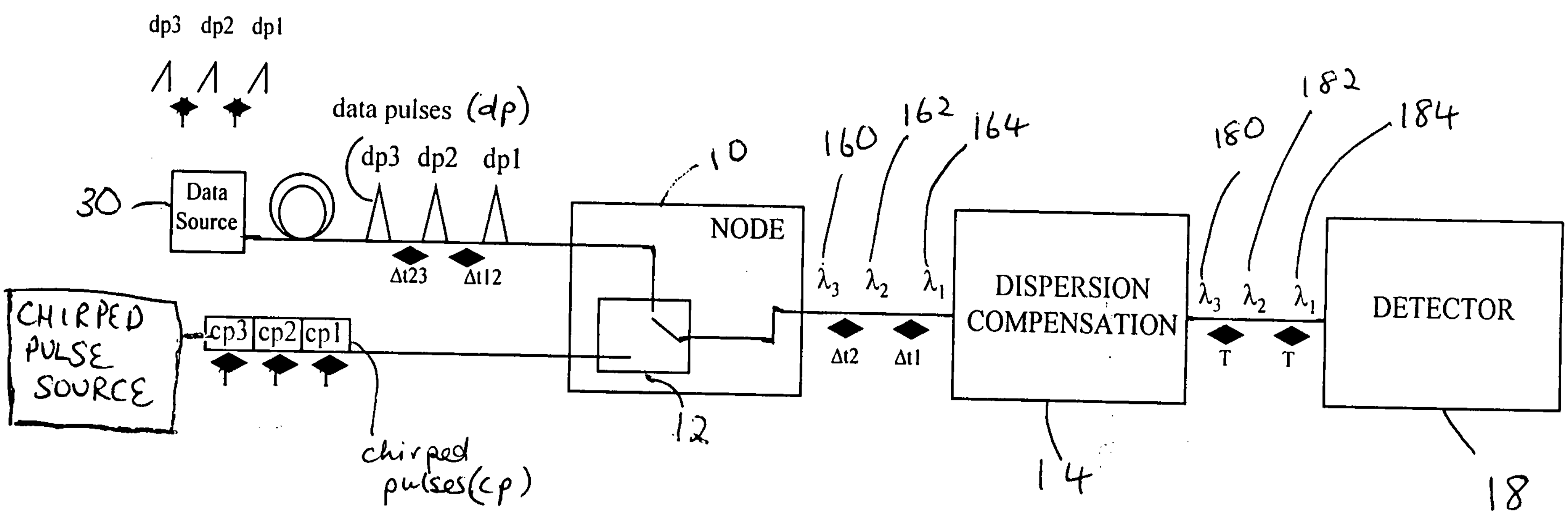
Figure 3



dp3 dp2 dp1
data pulses (dp)
dp3 dp2 dp1
30
Data Source
Δt23
Δt12
CHIRPED PULSE SOURCE
cp3 cp2 cp1
chirped pulses(cp)
10
NODE
12
160
162
164
λ3 λ2 λ1
Δt2
Δt1
DISPERSION COMPENSATION
14
180
182
184
λ3 λ2 λ1
T
T
DETECTOR
18

Figure 4

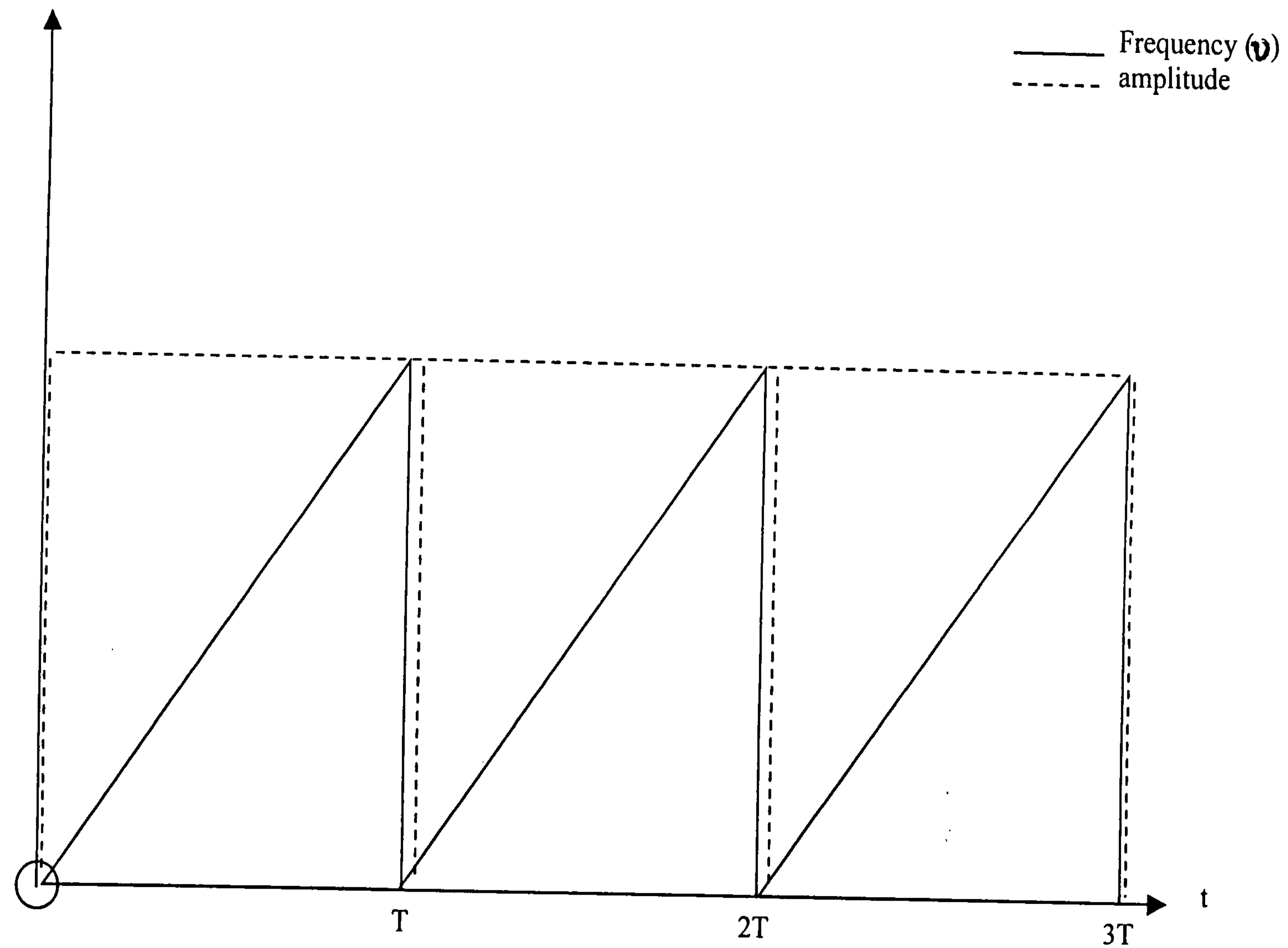


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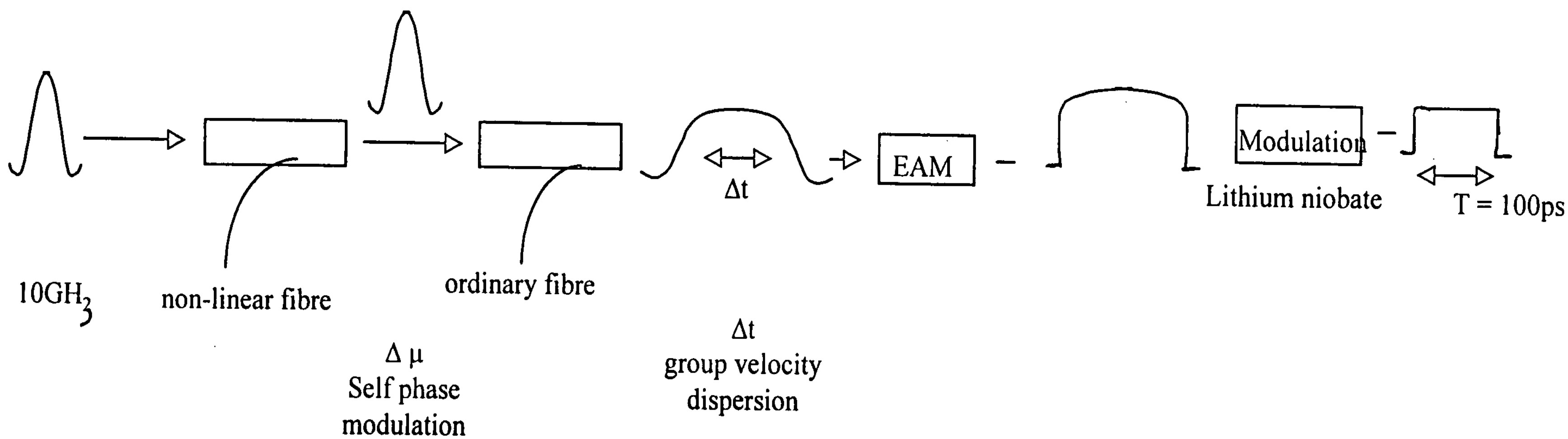
Figure 5



Δt
EAM
Modulation
Lithium niobate
T = 100ps
10GH₃
non-linear fibre
ordinary fibre
Δ μ
Self phase
modulation
Δt
group velocity
dispersion

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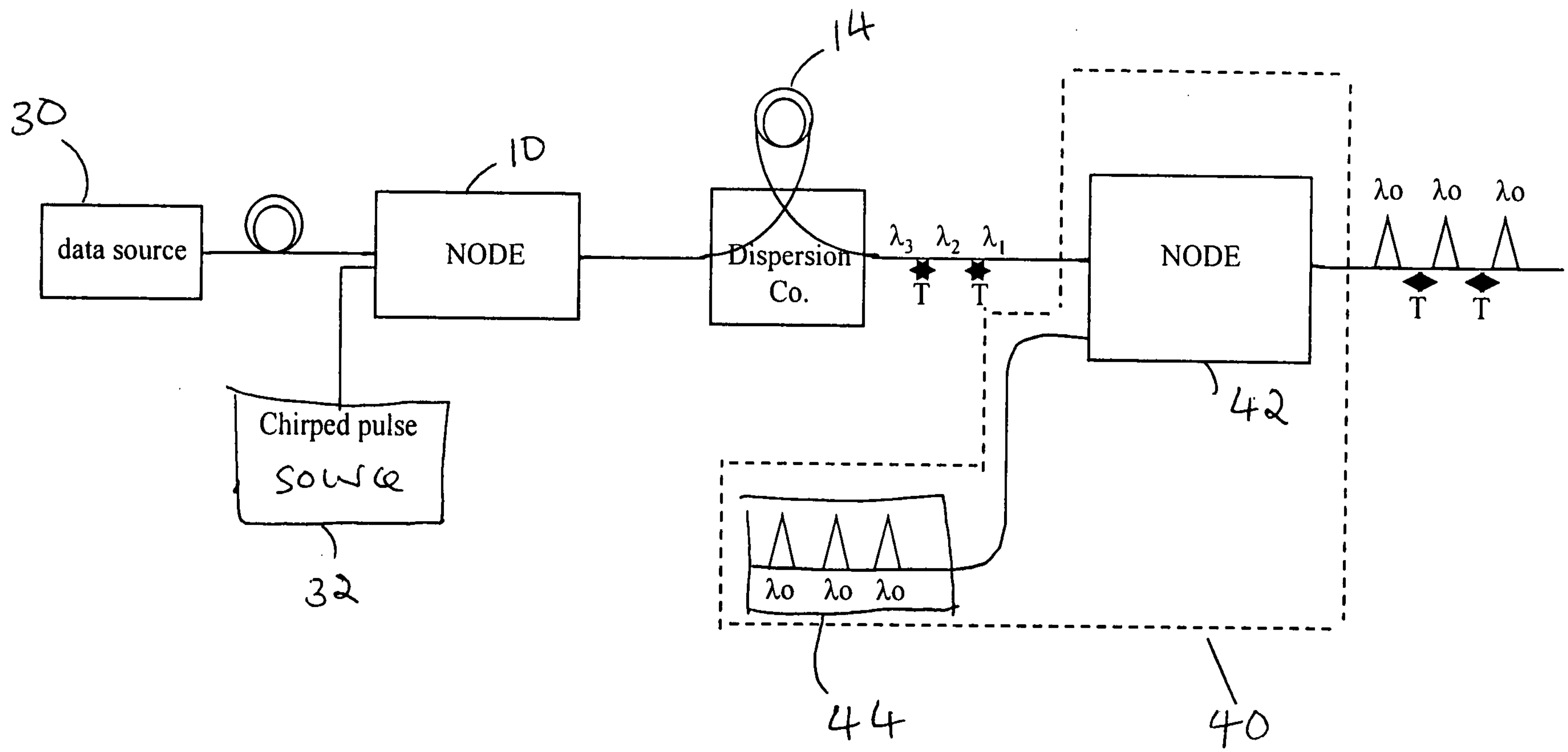
Figure 6



30
data source
10
NODE
Chirped pulse
sowce
32
14
Dispersion
Co.
λ_3 λ_2 λ_1
T T
NODE
42
λo λo λo
T T
λo λo λo
44
40

PCT/GB00/01155
BT.
27.3.00